EXTERNAL REVIEW DRAFT

POLLUTION PREVENTION

RESEARCH STRATEGY

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research planning process. It describes Office of Research and Development's strategy for conducting a research and development program in pollution prevention. The research strategy describes the long-term goals and strategic objectives that will be addressed over the coming five years. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ACRONYMS

ACS - American Chemical Society
CEA - Council of Economic Advisors
CENR - Committee on Environment and Natural Resources
CFCs - chlorofluorocarbons
CSI - Common Sense Initiative
DfE - Design for the Environment
DOD - Department of Defense
DOE - Department of Energy
DOT - Department of Transportation
EPA - Environmental Protection Agency
ETV - Environmental Technology Verification
GHGs - greenhouse gases
GPRA - Government Performance and Results Act
GWP - Global Warming Potential
HAPs - hazardous air pollutants
HFCs - hydrofluorocarbons
HFEs - hydrofluoroethers
HVAC - heating, ventilation, and air conditioning
IC - integrated controls
LCA - life cycle assessment
MACT - Maximum Achievable Control Technology
NAS - National Academy of Sciences
NCE - National Commission on the Environment
NRC - National Research Council
NSTC National Science and Technology Council
OAR - Office of Air and Radiation
OECA - Office of Enforcement and Compliance Assurance
OPPTS - Office of Prevention, Pesticides, and Toxic Substances
ORD - Office of Research and Development
OSWER - Office of Solid Waste and Emergency Response
OW - Office of Water
PBTs - persistent, bioaccumulative, and toxic chemicals
PCSD - President's Council on Sustainable Development
PERC - perchloroethylene
PPNT - Pollution Prevention and New Technology
PPOAs - Pollution Prevention Opportunity Assessments
SAB - Science Advisory Board
SRRP - Source Reduction Review Project
TEWI - Total Equivalent Warming Impact
TRI - Toxics Release Inventory
USDA - United States Department of Agriculture
USPS - United States Postal Service
UV - ultraviolet light
UV/TiO_2 - ultraviolet light/titanium dioxide
VOCs - volatile organic compounds
WCED - World Commission on Environment and Development
WRITE - Waste Reduction Innovative Technology Evaluation

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EXECUTIVE SUMMARY

The U. S. Environmental Protection Agency's (EPA's) Office of Research and Development (ORD) prepared a strategic plan which includes two priority long-term goals addressing prevention: to provide common sense and cost-effective approaches for preventing and managing risks, and; to provide leadership and encourage others to participate in identifying emerging environmental issues, characterizing the risks associated with these issues, and developing ways of preventing or reducing these risks.

Based on these goals, ORD developed a *Pollution Prevention Research Strategy* that elaborates on the directions in the strategic plan and provides a framework to guide investments in pollution prevention research and development over the next five years. The strategy contains four chapters; Chapter 1.0 sets the context; Chapter 2.0 outlines a strategic pollution prevention rationale; Chapter 3.0 describes four long-term goals and accompanying strategic objectives to be addressed and includes activities to be pursued as part of the research strategy; and Chapter 4.0 describes the implementation approach for the goals and objectives presented in Chapter 3.0. This executive summary is a capsule of the full document.

Context

Historically and currently, ORD has used EPA's definition of pollution prevention as "source reduction." In a broader sense, the National Commission on the Environment (NCE) offers a description of environmental sustainability that includes pollution prevention. The EPA definition and the NCE description were both central to the development of this research strategy. They provided the context from which ORD developed its strategic rationale for the research and development program that is outlined below.

ORD's pollution prevention activities in the early years focused on developing and evaluating technologies primarily through extramural funding of contracts, Cooperative Agreements, and Interagency Agreements. Once pollution prevention was established as an ORD program in 1988, this extramural focus began slowly shifting toward an in-house program devoted to research on tools, methodologies, and technologies. This shift has accelerated in the 1990s with the reogranization or ORD, causing it to focus on a smaller set of high priority activities where ORD scientists and engineers can make a significant contribution based on their unique knowledge, expertise, and capabilities.

As pollution prevention implementation has advanced in the past ten years, many of the problems most easily addressed using a preventive approach have been solved. With the "low hang fruit" having been picked, this leaves pollution prevention at a crossroads. Although progress in pollution prevention over the next ten years will not proceed as rapidly as in the past ten, the results can be even more significant, both in terms of research and development, and implementation. Since these next advances will represent more fundamental changes in individual

lifestyle, industrial process design, consumer products, and land use, future research and development must focus on quantum leaps instead of incremental improvements. These advances will not be achieved without a commitment by the public and private sectors to support long-term in-house research that can, if carefully planned, produce the needed technologies and tools that take pollution prevention to the next level.

Strategic Rationale

ORD's pollution prevention research strategy has been guided by a number of influential "voices"--among them, National Academy of Sciences, the Committee on Environment and Natural Resources, the National Research Council, the President's Council on Sustainable Development, and the American Chemical Society. ORD also used the Science Advisory Board's past contributions to the pollution prevention "dialogue" with the Agency to further focus its research strategy.

After considering guidance from the above organizations and narrowing the scope of the potential program to a subset of environmental problems and types of research and development where the the Agency can play a meaningful role, ORD investigated which issues were considered a high priority by EPA's Program Offices and Regions. The following themes emerged:

- ***Life cycle assessment and costing research*** **to provide the scientific basis for comparing alternative risk management approaches.**
- **Techniques to *measure pollution prevention effectiveness and verify the performance of pollution prevention technologies*.**
- **Pollution prevention approaches for the *agricultural sector*.**
- **Pollution prevention approaches to reduce *greenhouse gases,* including alternative energy (renewable) sources.**
- **Pollution prevention approaches for *targeted industries* (In most cases these were aligned with specific regulatory programs or Agency initiatives).**

These themes are reflected in the final research strategy. In addition to the outcome of consultations with EPA Programs, ORD determined that six priority setting criteria had to drive choices in research emphasis. Research priorities needed to: 1. *Address high risk human health or environmental problems*; 2. *Respond to the needs of stakeholders;* 3. *Fill important research and development gaps not being addressed by others*; 4. *Produce multimedia solutions that have wide applicability*; 5. *Apply knowledge, experience, and capabilities that reside within ORD;* and 6. *Leverage resources with other organizations.* The cumulative process led to the choice of the

four long-term goals and the associated strategic directions and priorities described below.

Long-Term Goals and Program Emphases

Long-Term Goal I: Developing and Testing Tools and Methodologies

ORD will develop, test, and provide tools and methodologies which improve individual and organizational decision making related so as to reduce or eliminate emissions, effluents, and wastes from products, processes, and activities.

Objective A -- Develop and test user-friendly tools and methodologies for improved decision making.

Research and Development Activities

New Activity -- Integrate risk assessment and risk management tools and methodologies:

- Linking risk assessment and pollution prevention tools.

Increased Emphasis -- Improve and develop generic tools and methodologies:

- Improving environmental engineering economics and cost tools.
- Improving the utility of life cycle assessments (LCAs).
- Developing process simulations tools.
- Developing pollution prevention progress measurement methodologies.
- Developing impact assessment tools.

Continued Emphasis -- Improve and develop targeted tools and methodologies:

- Providing decision support tools for municipal solid waste.
- Developing improved selection tools for surface treatment.

Long-Term Goal II: Developing and Evaluating Technologies and Approaches

ORD will develop and test pollution prevention technologies and approaches which are applicable across economic sectors, and evaluate products, technologies and approaches which are targeted at preventing high-priority human health and environmental problems in support of the Agency's regulatory and compliance programs.

Objective A -- Research, design, and assess novel and advanced environmentally benign approaches for industrial processing and manufacturing.

Research and Development Activities

Continued emphasis -- Chemistry for pollution prevention:

- Supporting fundamental research on chemistry.
- Developing and testing improved oxidation pathways.

Continued emphasis -- Engineering for pollution prevention:

- Supporting pre-competitive engineering research.

Continued emphasis -- Measurement, assessment, and feedback techniques for pollution prevention:

- Supporting prevention-related evaluation research.
- Developing intelligent controls for process operations.

Objective B. Develop and test technologies and approaches targeted at specific environmental problems.

Research and Development Activities

Continued Emphasis -- Address problems associated with metals and organics via separations technologies for in-process recycling:

- Developing separations for metals.
- Developing membranes for organic compounds.

Continued Emphasis -- Address problems associated with global warming to reduce Total Equivalent Warming Impact (TEWI):

- Investigating TEWI alternatives.

Continued Emphasis -- Address problems associated with VOCs and hazardous air pollutants (HAPs) by improving coating and cleaning operations:

- Developing new and innovative coating and cleaning chemistries and equipment.
- Adapting environmentally friendly coating and cleaning chemistries and equipment.

Increased Emphasis -- Address problems associated with products used indoors:

- Developing test methodologies and models.
- Supporting research on low-emitting materials and technologies..

Objective C. Demonstrate and evaluate pollution prevention in support of Agency and Program Office priorities.

Research and Development Activities

Continuing Emphasis -- Address problems associated with medium- and small-sized industries that pose high risk problems:

- Working in the metal finishing sector.
- Working in the printing sector.
- Working in the computer and electronics sector.
- Working in the auto refinishing sector.
- Working in the dry-cleaning sector.

Continuing Emphasis -- Support Agency rule makings and initiatives that encourage pollution prevention:

- Supporting the Office of Water.
- Supporting the Office of Air and Radiation.
- Partnering with other Program Offices.

Long-Term Goal III: Verifying the Performance of Cleaner Products, Technologies, and Approaches

As part of its Environmental Technology Verification (ETV) Program, ORD will serve as a catalyzing organization to propel into the marketplace the most promising commercial-ready pollution prevention products and technologies from both the public and private sectors.

Objective A -- Build a high-quality and efficient program to verify the performance characteristics of pollution prevention products and technologies

Research and Development Activities

Continued Emphasis -- Verify commercial-ready products and technologies which substantially reduce or eliminate the production of air, water, and waste products:

- Hazardous Waste Pollution Prevention and Treatment ETV.
- Industrial Coatings ETV Pilot.

- Metal Finishing ETV Pilot.
- Indoor Air ETV Pilot.
- Climate Change ETV Pilot.
- Air Pollution Prevention and Control ETV Pilot.
- Source Water Protection ETV Pilot.

Long-Term Goal IV: Conducting Research which Addresses the Economic, Social, and Behavioral Aspects of Pollution Prevention

Through its extramural grants program, ORD will sponsor economic, social, and behavioral research to improve decision making and foster the adoption of pollution prevention by the public and private sectors at all levels.

Objective A -- Develop and integrate social science and socioeconomic information and research products into environmental decision making

Research and Development Activities

Continued Emphasis -- Develop economic, social, and behavioral tools to improve environmental policies and programs:

- Understanding organizational decisions related to human health and environmental protection.
- Understanding the economic benefits of pollution prevention policies and programs.
- Understanding the economic costs of pollution prevention policies and programs.
- Developing relationships between economic growth and environmental quality.

Implementation

This research strategy provides the framework for an implementation plan which will lay out the systematic research and development activities to carry pollution prevention into the 21st Century and toward the realization of sustainable development. The success of that plan will be dependent on a number of variables, not the least of which is engagement and partnership with key stakeholders. It is essential that ORD work more closely with those who are directly involved in the implementation of pollution prevention approaches or influential in advancing the concept and routine consideration and use of preventive risk management. This includes EPA's Program Offices, the regulated sectors, and the following stakeholders:

- States, communities, and tribes in order to better understand those situations at the community level where pollution prevention might best be employed. It will also raise the profile of pollution prevention as a routine part of the Agency's approach to community-

based environmental decision making.

- Federal organizations in order to identify what research and development is needed to enhance the use of pollution prevention at federal facilities. It will also stress testing pollution prevention tools, methodologies, technologies, and approaches at government sites where they can be evaluated in real-world settings.

- The international community in order to exchange information on pollution prevention research and development and its implementation. It will also enhance perspectives on what other countries are doing to advance pollution prevention in the broader context of sustainable development.

ORD will use electronic technology (e.g., Internet home pages, distance learning) to the maximum extent possible as a means of engagement with stakeholders. The results developed by ORD will be designed to be available electronically, and ORD intends to be a major provider of pollution prevention research and development products via the Internet.

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1.0 INTRODUCTION

The U. S. Environmental Protection Agency's (EPA's) Office of Research and Development (ORD) has prepared a strategic plan which includes prevention as an important theme (1996a; 1997a). Two of the strategic plan's long-term goals specifically mention prevention as a priority:

> To provide common sense and cost-effective approaches for preventing and managing risks.
>
> To provide leadership and encourage others to participate in identifying emerging environmental issues, characterizing the risks associated with these issues, and developing ways of preventing or reducing these risks.

Based on the prominence of prevention in these two goals, it will be an integral part of ORD's future research program. The purpose of this document is to elaborate on the pollution prevention strategic directions outlined in the ORD strategic plan and to provide a framework within which to guide investments in pollution prevention research and development over the next five years.

What is Pollution Prevention?

The first step taken in developing this research strategy was to determine the types of activities which should be included in it. ORD has made judgements on the scope of activities to include based on its interpretation of EPA's working definition of pollution prevention (Habicht, 1992) (See Appendix I for the full definition):

> Pollution prevention means "source reduction" as defined under the Pollution Prevention Act, and other practices that reduce or eliminate the creation of pollutants through: (1) increased efficiency in the use of raw materials, energy, water or other resources, or (2) protection of natural resources by conservation.
>
> The Pollution Prevention Act defines "source reduction" as any practice which: (1) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and (2) reduces the hazards to public health and the environment with the release of such substances, pollutants, or contaminants.

Pollution prevention is national policy, embodied as "source reduction," in the Pollution Prevention Act of 1990 (West Publishing Co., 1992), and EPA's Administrator has declared pollution prevention to be the "guiding principle" of all EPA programs (EPA, 1993).

In a broader context, the National Commission on the Environment (NCE) (1993) described the role of pollution prevention in sustainable development (i.e., meeting the needs of the present without compromising the ability of future generations to meet their own needs [WCED, 1987]):

> Technology for sustainable development must focus on pollution prevention. This requires a total systems approach that prevents pollutants from being created in the first place or minimizes undesirable wastes and obviates the need for many controls. A preventive approach involves using fewer or non-polluting materials, designing processes that minimize pollutants or that direct them to other useful purposes, and creating recyclable products. The preventive/systems approach requires examining the full life-cycle of products and practices.

The NCE description integrates pollution prevention with environmental sustainability and offers the greatest opportunity for pollution prevention research and development in the future. A systems approach, where pollution prevention plays a critical role, is especially helpful in solving many of the remaining human health and environmental problems resulting from dispersed sources and individual activities. Both the EPA definition and the NCE description are central to the development of this research strategy.

The Evolution of ORD's Pollution Prevention Program

ORD has conducted a variety of research and development projects and programs over the last ten years which are consistent with the EPA definition of pollution prevention and the broader concept of sustainable development described above. The following are examples of research which has been conducted or is currently sponsored which further the goals embodied in the EPA definition and the NCE description:

> **CFC Alternatives:** With the United States agreement to reduce the production and use of chlorofluorocarbons (CFCs) under the Montreal Protocol, ORD undertook a research program to identify and evaluate alternative chemicals in technologies. Part of the effort targeted the synthesis of new chemicals (e.g., hydroflourocarbons (HFCs), hydrofluoroethers (HFEs)). Measurements were performed to establish the thermodynamic and thermophysical properties of these new chemicals and to determine their flammability, toxicity, and material compatibility. Other phases of the research investigated their performance in refrigeration and air conditioning applications and as foam blowing and fire extinguishing agents Similar activities were performed by industry for other chemicals. This collaborative effort resulted in a number of EPA and industry HFCs being successfully used in new equipment.
>
> **Waste Reduction Innovative Technology Evaluation (WRITE) Program:** Over the past seven years, ORD has investigated a number of waste minimization technologies and performed evaluations of these technologies to measure their pollution prevention effectiveness and costs. These evaluations were conducted in collaboration with six States and a county in New York. The targets were technologies for use by medium- and small-sized industries (electronics, printing, metal plating and finishing) and the evaluations addressed a number of processes (e.g., coating, painting, surface cleaning). Many of the evaluated technologies reduced or eliminated waste streams and resulted in

cost savings. It was also found that technology benefits (waste minimization and cost) were largely application-specific and that broad generalizations about technology application could not be made.

LCA Advancement: Life cycle assessment (LCA) principles provide an important conceptual framework within which to evaluate pollution prevention alternatives. ORD has been working to improve LCA tools and methodologies over the past five years and has undertaken a number of specific assessments to advance the understanding and application of life cycle thinking. As just one example, ORD worked with the lithographic printing industry to evaluate solvent substitutes in order to reduce volatile emissions. The findings of that effort revealed that a switch to low-VOC solvents can increase energy use and increase loading to air and water. The switch, in effect, resulted in shifting environmental burdens from the printers to elsewhere within the production system. ORD has developed LCA-oriented tools (e.g., P2 Factors Methodology, P2 Progress Methodology) as a means of advancing the cause of pollution prevention more broadly within an LCA framework.

Pollution Prevention Opportunity Assessments (PPOAs): ORD pioneered the development and application of PPOAs. PPOAs are a comprehensive examination of the operations at a facility with the goal of minimizing all types of waste products. Options are identified for the use of materials, processes, or practices that reduce or eliminate the creation of pollution or wastes at the source. Once a prevention option is identified, it is evaluated for technical, economic, and environmental feasibility. This analysis is not directly related to compliance standards, but by eliminating or reducing the sources of pollutants, the standards are automatically met or at least the compliance burden is reduced. Numerous PPOAs have been developed over the ten years (e.g., Fort Riley, Kansas; photo finishing facility; truck assembly plant) and these assessment documents have been widely adopted by the federal sector (e.g., DOE, DOD, USPS) for use at government facilities.

Source Reduction Review Project (SRRP) Support: Over the past five years, ORD has been supported the Agency's efforts at multimedia rule making under SRRP. SRRP is an effort to review Agency regulations during their earliest stages of development, and is designed to ensure that source reduction measures and multimedia issues are considered in air, water, and hazardous waste. SRRP focuses on key regulations during their development and encourages source reduction over add-on control technologies as the preferred approach to achieving environmental compliance. ORD has worked with the Office of Water (OW) to evaluate alternatives to chlorine bleaching in the pulp and paper industry and with the Office of Air and Radiation (OAR) to evaluate alternatives in reinforced plastics composite manufacturing, printing and publishing and wood furniture manufacturing.

Reducing Solvent and Propellant Emissions from Consumer Products: In some cases, an appropriate risk management strategy for reducing exposure to indoor air pollutants may be to develop a generic technology that will facilitate private sector development of low-emitting materials. A successful example of this is the development and evaluation of a new spray dispenser at Purdue University that was supported under an EPA Cooperative Agreement. The new design allows manufacturers to reformulate certain aerosol consumer products using air and water in place of solvents and hydrocarbon propellants while still maintaining acceptable product characteristics. Data collected thus far have shown that the dispenser's performance is nearly independent of product viscosity and surface tension. As a result, the dispenser design will be applicable to a wide variety of products. One particularly feature of this research is that the design guidelines for the dispenser will be generally available to all interested manufacturers (in late 1997), thus benefiting both small and large manufacturers worldwide.

In the early years, the majority of ORD's research and development activities focused on creating tools which other government agencies and the private sector could use to identify

pollution prevention opportunities (e.g., PPOAs, LCA Advancement), and on conducting evaluations of pollution prevention technologies through agreements with outside contractors or cooperators (e.g., WRITE Program, SRRP). A small percentage of the pollution prevention research program in the 1980s was focused on in-house research (e.g., CFC Alternatives). During this time, funding for pollution prevention research and development was provided from many dispersed sources and had to compete against all other important ORD research within a specific program area. Pollution prevention was formally established as a program within ORD in 1988 and received increased attention across the Agency (EPA, 1990b, EPA, 1992b). In the early to middle 1990s, ORD's pollution prevention research and development program primarily supported numerous EPA initiatives (e.g., 33/50 Program, SRRP, Common Sense Initiative) established to promote pollution prevention as the preferred approach for human health and environmental protection.

For the past several years, the ORD pollution prevention program has undergone a transition from an extramural program that promoted pollution prevention using targeted technical assistance and information transfer, to more of an in-house program devoted to scientific and technical research on pollution prevention tools, methodologies, technologies, and approaches. While this reorientation has not been seamless, it is well underway and will continue into the foreseeable future. Concomitant with a shift to an in-house research and development program, resource allocations have been reduced and targeted to support (i.e., infrastructure) that provides post-doctoral researchers, master's-degree assistants, technicians, and analytical services with which to build the in-house capabilities of ORD scientists and engineers. This shift has caused ORD to reevaluate its pollution prevention research and development priorities and to focus on a smaller set of high-priority activities where it can make a significant contribution based on its unique expertise and capabilities. ORD's extramural grants program has been engaged to provide the expertise and capabilities not resident within ORD.

Where is ORD's Pollution Prevention Research and Development Program Going?

While pollution prevention offers great opportunity for gains in human health and environmental quality, both in terms of research and development, and in commercial application, it appears to be at a crossroads. Some (Anderson, 1994; Roy, 1997) liken the state of pollution prevention to "having picked all of the low hanging fruit." Hirshhorn (1997) notes the passing of pollution prevention from a revolutionary force to an incremental tool. According to Pelley (1997), who interviewed industry researchers and practioners, pollution prevention research in the private sector has slowed, and the growth in field applications has the potential to stagnate in the coming years. Pelley explains why this is so: (1) reluctance to employ expensive new technologies that don't have a short-term economic payoff, (2) lack of a regulatory motivation from either EPA or the states, and (3) reduction in government funding of pre-competitive technologies that are less polluting.

ORD believes that pollution prevention progress in the next ten years will not proceed as

rapidly as in the past ten, but the results of that progress can be even more significant. The "next wave" of pollution prevention can provide economic and environmental benefits in a host of situations. Since these advances will likely represent more fundamental changes in individual lifestyle, industrial process design (e.g., clean technologies), consumer products (e.g., benign chemicals), and land use, future research and development must focus on quantum leaps instead of incremental improvements. ORD will only be able to sustain this future direction if it concentrates on longer-term research which will produce a new generation of tools and technologies to move pollution prevention beyond the "low hanging fruit." These advances will not be achieved without a commitment by both the public and private sectors to support long-term in-house research programs which can, if carefully planned, produce the technologies and tools that are needed.

Structure of this Research Strategy

This research strategy, while oriented toward the classic Agency definition of pollution prevention, recognizes that over the longer term, pollution prevention should be viewed in the context of sustainable development, and must move in the direction of addressing the highest priority human health and environmental problems. It is divided into four chapters with Chapter 1.0 (this chapter) setting the scene and arguing for a broad view of pollution prevention research and development. Chapter 2.0 presents an analysis of the pollution prevention research and development situation which leads to five Key Questions that must be answered in the coming years. Chapter 3.0 describes four long-term goals and accompanying objectives that will be addressed by ORD; this chapter includes the research and development activities and project areas that will be pursued as part of this research strategy. Finally, Chapter 4.0 describes, in general terms, the allocation of resources and emphases over the coming five years for the four long-term goals and associated objectives presented in Chapter 3.0.

2.0 STRATEGIC RATIONALE FOR THE ORD POLLUTION PREVENTION RESEARCH AND DEVELOPMENT PROGRAM

Pollution prevention is a broad area of research and development which can be used in many economic sectors to reduce or eliminate releases of environmental contaminants. Both the public and private sectors must support pollution prevention research and development in the future if it is to be widely applied as the preferred approach for managing human health and environmental risks. The breadth of pollution prevention and the possibilities for the research and development needed pose a significant challenge. Both ORD and other research organizations must elect to focus on only a limited number of research and development activities due to financial and human resource limitations. This chapter of the research strategy explains the rationale used by ORD to select priority areas to focus on over the next five years.

Why is Pollution Prevention An Important Future Research Priority?

While significant advances have been made, many gaps in knowledge still impede the widespread adoption of preventive risk management. Pollution prevention research and development is a relatively new field of endeavor when compared to other areas such as research and development of end-of-the-pipe control technologies. Pollution prevention research and development has largely focused on the industrial sector of the economy. Numerous authors (Freeman, et. al., 1992; Freeman, 1995; INFORM, 1995; Pelley, 1997) stress the important role that pollution prevention plays in reducing toxic releases and exposure to chemicals in wastes. According to the 1994 Toxics Release Inventory (TRI), billions of pounds of chemicals were released, transferred, or disposed of in wastes from industrial facilities that year (Appendix II). Releases will grow in the coming years with the expansion of the TRI (Federal Register, 1996). This growth in chemical releases, along with an expanding world population and global economy, provide the impetus for a focus on prevention research and development.

Protecting human health and the environment into the 21st Century must stress the prevention of pollution before it occurs, and should realistically look beyond the TRI-listed chemicals for ways to contribute to reducing human health and environmental risks. Ehrenfeld and Howard (1996) make the point that a number of American industries have already recognized the need to address environmental protection in a more holistic and systematic manner by emphasizing design for the environment (DfE) and industrial ecology. Hart (1997) identifies pollution prevention as the first step (Stage One) that most companies take when moving away from pollution control. Stage Two is product stewardship (e.g., DfE, life cycle assessment). Stage Three is clean technology -- where fundamental shifts in both products and processes are designed and implemented -- a stage that may require several decades before being broadly accepted and practiced.

Guidance on Pollution Prevention Research Priorities from External Organizations

The most important consideration in designing this research strategy was the determination of where ORD could make the most significant contrihbutions to the field. The first factor considered was the role of federal research and development in addressing issues of national concern. The National Academy of Sciences (NAS, et.al. 1995) provided its perspective on this issue when it stressed that resources invested by the federal government in science and technology help build the base of scientific and technical knowledge and expertise used by both government and industry to address important national goals (e.g., national defense, space exploration, economic growth, and protection of public health and the environment). The National Science and Technology Council (NSTC, 1994) supported a similar perspective when it identified the important role the federal government plays in funding basic and applied research and development keyed to future generations of environmental technologies. This latter report also stressed the role that the federal government can play in facilitating private sector investment by reducing the uncertainties caused by regulatory, verification, and permitting processes.

Based on these broad national level perspectives, ORD has concluded that there is a need for federal research to facilitate the development and acceptance of new products, processes, or management practices which pose less of a hazard to human health and the environment. The ultimate goal is to ensure that adequate research and development has been conducted which will provide the information and data required to design new products and processes that are inherently less polluting. ORD is in a unique position to focus federal pollution prevention investments because: (1) it is the only federal research organization with the broad mission to ensure that the pollution prevention adopted provides maximum human health and environmental protection, and (2) it has direct links to the regulatory and compliance offices of EPA to ensure that pollution prevention research and development activities are focused on the nation's highest priority human health and environmental problems.

Pollution Prevention in Strategic Plans and National Strategies

In the past three years, a number of committees, councils, academies, and EPA have offered their opinions on strategic directions for environmental protection (EPA, 1994; CENR, 1995; PCSD, 1996; ACS, 1996; NRC, 1996). There is a mix of pollution prevention priorities in these five strategies. Clearly, EPA's five-year strategic plan views pollution prevention as an overarching means of accomplishing a number of environmental goals, from improving air quality to promoting worker safety. Strategies of the Committee on Environment and Natural Resources (CENR), the American Chemical Society (ACS), and the National Research Council (NRC) stress technological solutions via cleaner chemicals, clean technology, environmentally preferable products, prevention technologies and practices, industrial ecology, chemical-specific separations, and catalytic systems. The President's Council on Sustainable Development (PCSD) and the NRC strategies also support the development of improved analytical tools including cost/benefit analysis associated with risk assessment. Both of these strategies address the need for economic,

social, and behavioral research that advances the concept of sustainable development.

Pollution Prevention and the Science Advisory Board

Over the years, the EPA's Science Advisory Board (SAB) has provided guidance on the relative risks of environmental problems. ORD has reviewed its most recent report on this topic (EPA, 1990a) to further focus its proposed strategy on the most important environmental problems. Figure 1. lists these high-priority problem areas. In addition to studies which rank the relative importance

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High-Priority Human Health Risks

Ambient Air Pollutants
Worker Exposure to Chemicals in Industry and Agriculture
Pollution Indoors
Pollutants in Drinking Water

High-Priority Risks to Natural Ecology and Human Welfare

Habitat Alteration and Destruction
Species Extinction and Overall Loss of Biological Diversity
Stratospheric Ozone Depletion
Global Climate Change

Figure 1. High Priority Human Health and Environmental Risks Identified by the SAB (EPA, 1990a).

of environmental problems, the SAB has also provided commentaries on past Agency pollution prevention reports and strategies. These commentaries provided insights on what the SAB considered to be important pollution prevention research and development activities, and identified the highest priority environmental problems which EPA should emphasize. The first commentary (EPA, 1989) was prepared as part of the SAB's review of a draft of the *Pollution Prevention Research Plan: Report to Congress* (EPA, 1990b). The second commentary (EPA, 1992a) was prepared as part of the SAB's review of a draft of the *Pollution Prevention Research Program* (EPA, 1992b). The SAB stressed the need for social science research (non-technological) in both of its commentaries, as well as the need for a means of measuring the progress of pollution prevention. The need to address non-industrial pollution prevention was raised with respect to agricultural and mining practices, with a particular concern regarding pesticides. There was also a call for increased coordination with other organizations to advance pollution prevention and to facilitate communication and technology transfer. Finally, there were

calls for product research, environmental professional training, anticipatory research on future environmental problems, and consistency in prioritizing research activities. These commentaries and the relative ranking of environmental problems influenced the priorities detailed later in this document.

Guidance on Pollution Prevention Research Priorities from Internal Organizations

After carefully considering the guidance from outside organizations, the scope of the potential pollution prevention program which ORD plans to conduct was narrowed to a subset of environmental problems and types of research and development where the federal government can play the most effective and significant role (i.e. broadly applicable tools and methodologies, generic and enabling technologies and approaches). The next step was to investigate which of these problem areas or types of research were considered a high priority by other organizations within EPA. ORD conducted a survey of selected staff in the Office of Prevention, Pesticides and Toxic Substances (OPPTS), Office of Air and Radiation (OAR), Office of Enforcement and Compliance Assurance (OECA), Office of Policy, Planning and Evaluation (OPPE), Office of Water (OW), Office of Solid Waste and Emergency Response (OSWER) and the Regions. By engaging Program Offices and Regions, ORD was able to sharpen its focus. The following themes emerged from the survey:

- **ORD research should emphasize *life cycle assessment and costing research* in order to provide the scientific basis for comparing alternative risk management approaches.**
- **Techniques to *measure pollution prevention effectiveness and verify the performance of pollution prevention technologies* are needed to assess the environmental reductions which are being achieved.**
- **Pollution prevention approaches are needed for the *agricultural sector* to reduce releases into several media.**
- **Pollution prevention approaches to reduce *greenhouse gases,* including alternative energy (renewable) sources are needed.**
- **Pollution prevention approaches are needed for *targeted industries in the industrial sector* (In most cases these were aligned with specific regulatory programs or Agency initiatives).**

The Program Offices were very consistent in identifying needs in several areas. First, there was a need to develop and test tools and methods to measure the performance of various pollution prevention approaches (i.e., to what degree is pollution actually reduced by prevention), and to verify pollution prevention technology performance. Second, there was a clear desire for ORD to work closely with the Program Offices in advancing pollution prevention either voluntarily, or as part of a rule making or compliance activity. In addition to targeting industries, there was a call to address greenhouse gas emissions and agriculture via pollution prevention

research, and to conduct research in partnership with industry and other stakeholders.

Key Scientific and Technical Questions

The above strategic analysis led to the development of the following five key scientific and technical questions:

A. What are the analytical and process tools that will allow stakeholders at all levels to make more informed decisions on prevention technologies and approaches so that measurable progress can be made in human health and environmental protection from the local to the global level?

B. What are the products and processes that by their very design can prevent and reduce the formation and release of toxic pollutants that are high risks to both human health and the environment?

C. What are the technologies and approaches that can prevent and reduce the formation and release of toxic pollutants that are high risks to both human health and the environment?

D. What pollution prevention technologies, processes, and products should be verified in order to more quantitatively measure their human health and environmental benefits?

E. What are the economic, social, and behavioral, issues that affect individuals and communities (from families to nations) so they can better understand the benefits and limitations of using a preventative approach to managing risks?

These key questions are helpful in identifying research opportunities and setting long-term goals for the research strategy. To assist in further focusing ORD's research and development activities in pollution prevention, these five key questions must now be considered within the context of where ORD can make a difference.

Evaluation of ORD Capabilities and Expertise

After considering the external and internal guidance described above, ORD further refined its pollution prevention focus by evaluating its potential contribution in terms of the environmental

problems of greatest significance and the economic sectors which contribute to those problems. This research strategy, recognizes a sector-based approach as a way to organize pollution prevention research and development activities. An economic sector can be defined as a grouping of enterprises that produce similar goods and services. Table 1. graphically represents which economic sectors contribute to each of the high-priority environmental problems. The broad economic sectors identified are ones traditionally associated with pollution prevention applications (EPA, 1991, Habicht, 1992): industrial, agricultural, consumer, energy, and transportation. As can be seen in Table 1. (note shaded boxes), ORD has resident capabilities in the industrial sector, and more limited capabilities in the consumer and energy sectors. ORD has little capability in the agriculture, energy, and transportation sectors and would look to the U. S. Department of Agriculture (USDA), the Department of Energy (DOE), and the Department of Transportation (DOT) to support pollution prevention research and development for these sectors.

Criteria for Setting Pollution Prevention Research and Development Priorities

Six criteria were developed to further refine the focus of ORD's pollution prevention research and development program, taking into account: (1) the general areas where research and development in pollution prevention could significantly advance its application based on the strategic analysis, and (2) the expertise and resources within ORD that are available to address pollution prevention.

1. *Addresses High-Risk Human Health or Environmental Problems.* The desire is to conduct projects targeted at high risk human health and environmental problems, but not to exclude a perceived problem based solely on the lack of available data.

2. *Responds to the Needs of Stakeholders.* The desire is to conduct research and development activities that are relevant to those with a stake in the pollution prevention arena, both within EPA and, increasingly, to others as the Agency moves from a command-and-control approach to a community-based approach for environmental protection.

The SAB's High Priority Human Health and Environmental Risks (after SAB, 1990)	Contributing Economic Sectors					
	Industrial Sector	Agricultural Sector	Consumer Sector	Energy Sector	Transportation Sector	Pollution Prevention
Human Health Risks						
Ambient Air Pollutants	✓	✓	✓	✓	✓	Yes
Worker Exposure to Chemicals in Industry and Agriculture	✓	✓		✓		Yes
Pollution Indoors	✓		✓		✓	Yes
Pollutants in Drinking Water	✓	✓	✓	✓	✓	Yes
Environmental Risks						
Habitat Alteration and Destruction	✓	✓	✓	✓	✓	Yes
Species Extinction and Overall Loss of Biological Diversity	✓	✓	✓	✓	✓	Yes
Stratospheric Ozone Depletion	✓	✓	✓		✓	Yes
Global Climate Change	✓			✓	✓	Yes

Table 1. The Economic Sectors that Contribute to the SAB's High-Priority Human Health and Environmental Risks.

3. *Fills Important Research and Development Gaps not being Addressed by Others.* The desire is to avoid duplication of pollution prevention research and development activities being conducted by others, while at the same time recognizing that either for regulatory reasons, or because there are no other champions, ORD will be the organization that conducts a variety of pollution prevention research and development activities.

4. *Produces Multimedia Solutions that Have Wide Applicability.* The desire is to

focus on long-term solutions in the arena of pollution prevention research and development activities which by design have wide applicability, while at the same time recognizing that in a regulatory agency, there are very targeted, media-specific research and technical assistance needs that must be addressed in response to short-term deadlines associated with laws, regulations, and policy.

5. *Applies Knowledge, Experience, and Capabilities that Reside within ORD.* The desire is to maintain or, better still, strengthen the knowledge, experience, and capabilities within ORD to address pollution prevention research and development activities, while at the same time recognizing that other organizations can make meaningful contributions to a broadened program.

6. *Leverages Resources with Other Organizations.* The desire is to stress leveraging of resources and capabilities with others, while at the same time recognizing that as a regulatory agency not all pollution prevention research and development activities can, or will, be supported by the various stakeholders.

Strategic Approach

Based on a careful consideration of all the above factors, ORD has chosen to focus its pollution prevention research and development program in four major areas:

- First, the program will develop tools and methodologies which can be used to promote pollution prevention across the problems and sectors listed above. ORD will invest in this area because it has substantial experience developing such tools and methodologies, and in several areas (e.g., life cycle analysis, process simulation) ORD staff are recognized for their expertise and capabilities. The unique Agency mission to advance the use of prevention and ensure that the tools and methodologies effectively consider multiple environmental impacts makes this an inherently EPA research and development responsibility.

- Second, the program will develop and evaluate pollution prevention technologies and approaches. This area is focused on those environmental problems and sectors of the economy where the external guidance recommends emphasis and where other EPA offices have the greatest needs. Within the industrial sector, there is a particular need for research to support medium- and small-sized industries that are geographically dispersed (e.g., dry cleaners, metal finishing, printing). This is also true for larger industries that have difficulty in meeting compliance requirements. ORD has resident expertise which can be applied to the environmental problems associated with the industrial and consumer sectors and intends to maintain that expertise in the coming years. In many of these areas, ORD has internationally recognized scientific and technical staff who can make contributions in the science and technical arenas leading to resolution of regulatory and compliance issues.

Increasing emphasis will be on generic technologies and approaches which have the potential to cut across a number of sectors, and ORD is the logical champion for such developmental work. Industry and other government agencies are focused more on developing pollution prevention options for specific processes which are of the greatest concern to them. ORD can be very influential in catalyzing the development of technologies and approaches through leveraging resources and partnering with stakeholder organizations.

- Third, the program will verify the performance of pollution prevention alternatives in order to fully demonstrate their efficacy, particularly as noted by the Program Offices. This is a critical research need because one of the most significant factors limiting the use of pollution prevention approaches is the lack of confidence by both industry and regulators that they can achieve required reductions through pollution prevention. Over the past five years, ORD has developed a capability to verify commercial-ready technologies and products. ORD will maintain this capability over the coming five years, and if needed, grow in areas where verification can make a contribution to human health and environmental protection. Pilot verification entities have been funded to support technology verification targeted at high-priority human health and environmental risks.

- Fourth, the program will investigate the economic, social, and behavioral (i.e., non-technical) aspects of pollution prevention to better understand, and then ameliorate, the barriers to the adoption of pollution prevention technologies and approaches in the future. Such has been called for by several of the national strategies and the SAB. There is very limited capability within ORD to address these issues (e.g., economics), but because there is such a strong need for this research the extramural grants program will be used to address this important area. ORD resident capabilities will be expanded in economics, while other social science capabilities will be garnered through the competitive grants program. The results of this effort have the potential for broad applicability and the National Science Foundation has leveraged resources in the social science arena in the past.

Each of these major areas is developed in greater detail in Chapter 3.0 in the context of a long-term goal with associated objectives. Each objective includes a set of research and development activities that will be undertaken along with brief descriptions of project areas that will be pursued.

3.0 ORD'S POLLUTION PREVENTION RESEARCH AND DEVELOPMENT PROGRAM

Vision

This research strategy is designed around the following vision of where ORD's Pollution Prevention Research and Development Program should be going in the future:

> ***Scientifically based pollution prevention research and development products will be used routinely by communities, industries, governments, and other stakeholders for improved environmental decision making on high-risk human health and environmental problems, and as part of a move toward sustainable development in the 21st Century.***

Mission

In moving toward this vision, ORD's Pollution Prevention Research and Development Program mission is:

> ***To advance scientific research and develop cost-effective tools, methods, technologies, and approaches which expand the availability and use of pollution prevention by both the public and private sectors.***

Long-Term Goals

In support of our vision and mission, and in concert with the strategic approach identified in Chapter 2.0, the following will be pursued in this research strategy:

> ***I. ORD will develop, test, and provide tools and methodologies which improve individual and organizational decision making related so as to reduce or eliminate emissions, effluents, and wastes from products, processes, and activities.***
>
> ***II. ORD will develop and test pollution prevention technologies and approaches which are applicable across economic sectors, and evaluate products, technologies and approaches which are targeted at preventing high-priority human health and environmental problems in support of the Agency's regulatory and compliance programs.***
>
> ***III. As part of its Environmental Technology Verification (ETV) Program, ORD will serve as a catalyzing organization to propel into the marketplace the***

most promising commercial-ready pollution prevention products and technologies from both the public and private sectors.

IV. Through its extramural grants program, ORD will sponsor economic, social, and behavioral research to improve decision making and foster the adoption of pollution prevention by the public and private sectors at all levels.

Figure 2. provides a visual frame of reference within which the research and development program will be achieved. Additional details on each of the four long-term goals are provided in this section including specific objectives that ORD will pursue over the next five years. For each objective, details are provided on: (1) why research is important (Rationale), (2) what the current situation is with respect to the long-term goal and objective (Current Situation), and (3) what research and development activities are planned. Each long-term goal description concludes with a discussion on projected resource allocations (Resource Allocation and Emphasis).

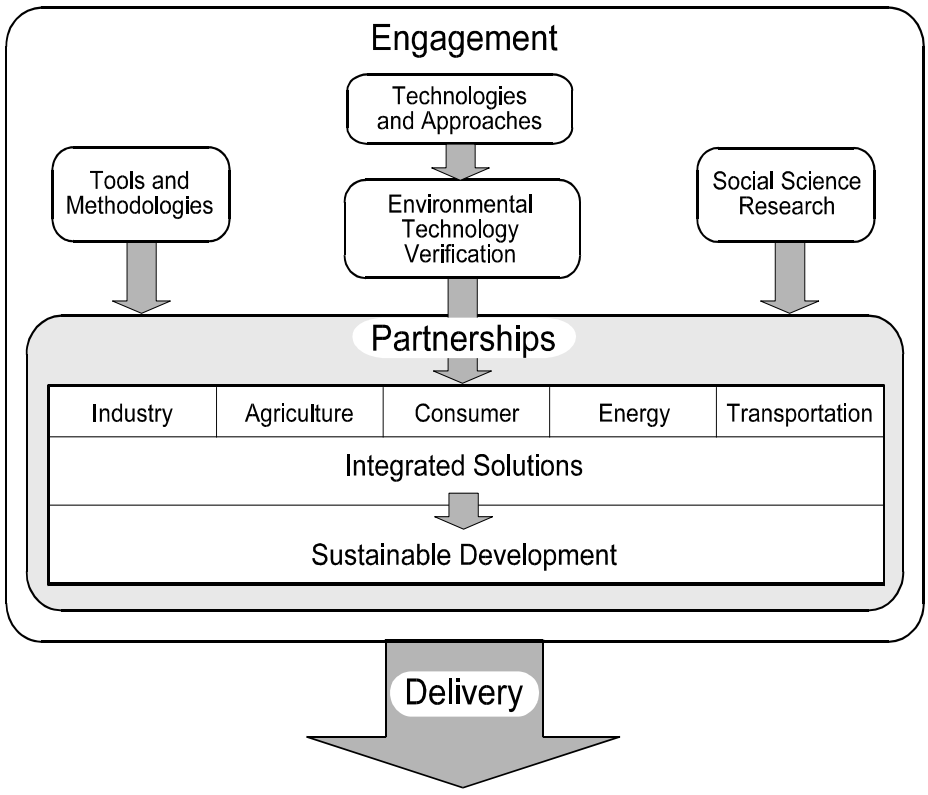

Figure 2. Framework for ORD's Pollution Prevention Research Strategy.

Long-Term Goal I: Developing and Testing Tools and Methodologies

ORD will develop, test, and provide tools and methodologies which improve individual and organizational decision making related so as to reduce or eliminate emissions, effluents, and wastes from products, processes, and activities.

Objective A. Develop and test user-friendly tools and methodologies for improved decision making.

Rationale

As many of the human health and environmental problems most amenable to pollution prevention are addressed, the need for scientifically-sound, user-friendly tools and methodologies to assist in making decisions on complex risk management problems becomes increasingly important. These tools and methodologies can be of invaluable assistance for identifying and evaluating technologies and approaches that are less polluting when compared to each other, or to more traditional end-of-the-pipe treatment. They provide regulators, industries, and environmental organizations with an increased confidence that the decisions made can effectively take into account both the important economic, and human health and environmental considerations associated with pollution prevention. For pollution prevention to play a key role both now and in the future, tools and methodologies must be developed that are more quantitative in nature. Developing and testing pollution prevention tools and methodologies that are easy to use and meaningful to stakeholders allows for improved decision making at all levels.

Current Situation

Today's decision makers are faced with difficult choices in managing human health and environmental risks. There is a paucity of tools and methodologies available to assist them in considering the technical, political, legal, or socioeconomic implications of their decisions, and how effective those decisions can be in reducing human health and environmental problems. All too often, environmental impacts are not considered beyond a very narrow realm, and risk management options are not thoroughly characterized using such tools as life cycle assessment, process simulation, and cost/benefit analysis. What on the surface appears to be the best option, may not consider either the complete life cycle of a product or process, or the risks of trading one pollution problem for another. While ORD has made some progress in developing and testing pollution prevention tools and methodologies, additional efforts are needed which permit decision makers to better quantify human health and environmental impacts and better manage high priority risks.

Research and Development Activities

1. New Activity -- Integrate risk assessment and risk management tools and methodologies

Increasingly, EPA is being asked by Congress, the Administration, and the public to consider risk when promulgating regulations and developing rules. Past research and development efforts have improved the ability of the Agency to use quantitative risk assessment in making decisions on high-risk human health and environmental problems. The ability to link risk assessment and risk management tools that permit the analysis of possible options both environmentally and economically is now being called for by the National Research Council (1996). Such an approach is a logical next step in using scientific and technical information to make more informed decisions on risks and risk management.

Linking risk assessment and pollution prevention tools. ORD's National Center for Environmental Assessment and National Risk Management Research Laboratory will develop and pursue a joint program to link, and if appropriate, integrate risk assessment methodologies and pollution prevention tools (e.g., LCA, cost/benefit analysis) to improve decision making on important human health and environmental problems. This research will test the ability of risk assessors and risk managers to develop tools and methodologies which are meaningful and understandable to the public in terms of the costs and benefits associated with the magnitude of the risk that is identified. This is a long-term effort that will require the development and improvement of quantitative risk assessment and cost/benefit analysis or similar tools. Together, these tools will provide a more robust and reliable means of making decisions on human health and environmental risks.

2. Increased Emphasis -- Improve and develop generic tools and methodologies

Technologies and approaches for preventing or reducing human health and environmental risks should be reliable, cost-effective, technically sound, and acceptable. As pollution prevention advances and a move toward sustainable development progresses in the coming years, ORD must assist public officials and the private sector in making decisions on which new technologies and approaches will be the most effective, both economically and environmentally. The research and development conducted will: (1) improve engineering economy and cost tools, (2) refine and advance the utility of life cycle analysis, (3) develop process simulation tools, (4) develop pollution prevention progress measurement methodologies, and (5) develop and improve impact assessment tools. Work under this activity will be conducted both in-house and as part of an extramural grants program.

Improving environmental engineering economics and cost tools. ORD will investigate and develop improved costing protocols and cost-assessment techniques. These protocols and techniques can then be used in concert with various decision making tools and methodologies to measure the human health and environmental costs and benefits

associated with various pollution prevention risk management options. A portion of the research in this area will focus specifically on how to improve the techniques currently used to estimate the capital and operating costs of new pollution prevention approaches.

Improving the utility of life cycle assessments (LCAs). ORD will improve the utility of LCAs and advance "life cycle thinking" to a point where it is more routinely used in judging risk management options which prevent pollution. Because a complete and exhaustive LCA is extremely difficult to achieve and very expensive, efforts will focus on the inventory phase of LCAs which tends to be both labor and cost intensive. ORD will investigate less-intensive and more-economical approaches for analyzing inventory data and information (including issues associated with inventory data quality) including the use of indirect or surrogate measures (e.g., input/output econometrics data) and methodologies. These surrogates will then be incorporated into the life cycle framework as a preliminary means of comparing various preventive risk management alternatives.

Developing process simulations tools. ORD will develop, field test, and improve computerized simulation tools (e.g., process simulation software, solvent design software) which can be used by facility designers or operators to reduce wastes and seek less-polluting chemical and process alternatives building on past successes in this area. These tools will specifically quantify waste generation and environmental impact potential associated with alternative design approaches or materials selection so that pollution prevention considerations are automatically integrated into the design process. As part of this effort, the application of simulation to materials other than solvents will be investigated. ORD will also move into the arena of industrial ecology where simulations can be applied to a set of processes or operations across a facility, or to a collection of facilities which are interdependent (e.g., one facility's waste is another facility's feedstock).

Developing pollution prevention progress measurement methodologies. ORD will develop and refine methodologies to measure progress in environmental improvement when pollution prevention is employed (e.g., toxic organics prevented, global warmers eliminated, nutrients reduced, hazardous wastes minimized). This methodology will take into account concurrent pollution increases which may occur, energy-related pollution associated with the preventive action, and impacts on compliance with various EPA regulations, eventually relating pollution prevented to associated cost (e.g., environmental and/or health risks prevented per dollar spent). ORD will concentrate on developing user-friendly methodologies that are applicable across the LCA spectrum (e.g., raw material acquisition and handling, packaging and distribution, use, disposal).

Developing impact assessment tools. ORD will develop and improve tools and methodologies to assess the impacts of pollution prevention alternatives based on a series of impact categories. Specific categories which are currently being investigated for

potential chemical emission impacts include: ozone depletion potential, global warming potential, acidification potential, photochemical oxidation potential, human health impact potential and environmental health impact potential. While some of these categories (e.g., ozone depletion and global warming) have an international consensus on impact potential calculation and the databases necessary to support them, most of the categories do not. Work will also begin in the later years of this research strategy on non-chemical impacts (e.g., resource depletion, habitat alteration, biodiversity).

3. Continued Emphasis -- Improve and develop targeted tools and methodologies

ORD has a continuing commitment to support various Program Offices in the development and evaluation of tools and methodologies that advance pollution prevention in specific areas or for specific problems. The research and development to be conducted will be in support of : (1) the Office of Solid Waste and Emergency Response (OSWER) on municipal solid waste, and (2) the Office or Air and Radiation (OAR) on volatile organic chemical substitutes. ORD will support other Program Offices that would benefit from the tools and methodologies under development and testing by ORD scientists and engineers as the need arises.

Providing decision support tools for municipal solid waste. ORD will continue developing a tool which provides federal, state, and local governments and interested stakeholders in the private sector with the capability to compare the life cycle implications of competing solid waste management strategies. Environmental and economic data will be collected for individual municipal solid waste management operations and upstream manufacturing operations including associated transportation impacts. Procedures will be developed to understand the interrelationships of different system components, including upstream components critical to evaluating source reduction and recycling options as compared to other waste management options such as combustion, composting, and landfilling.

Developing improved selection tools for surface treatment. ORD will continue to improve practical tools to assist in selecting substitute materials, products, or processes for surface treatment (e.g., Adhesives Alternatives Guide, Solvents Alternatives Guide) and will explore the possibility of expanding the guides into areas other than surface treatment. These tools are designed to provide information to medium- and small-sized businesses for their use both directly and through technical assistance providers. These tools provide the user with recommendations on already developed and demonstrated technologies. They are based on the technical and scientific parameters of the processes which are then matched against characteristics and requirements of the products in order to recommend a less-polluting alternative.

Resource Allocation and Emphasis

Long-Term Goal I will receive increased emphasis under this research strategy. Providing user-friendly tools and methodologies for improved decision making on pollution prevention risk management alternatives is extremely important. This is particularly true as the Agency moves from a command-and-control approach of environmental protection to one that is oriented around environmental decision making at the community level. As a federal environmental research organization, ORD has the responsibility for conducting research and development in this area and is well positioned to do so in terms of both staff knowledge, expertise, and experience, and supporting financial resources. As ORD moves toward achieving this goal, increased staffing and financial resources will be directed into the tools and methodologies area. If necessary, additional resources will be solicited as part of the Agency's planning and budgeting process to ensure progress in meeting this long-term goal.

Long-Term Goal II: Developing and Evaluating Technologies and Approaches

> **ORD will develop and test pollution prevention technologies and approaches which are applicable across economic sectors, and evaluate products, technologies and approaches which are targeted at preventing high-priority human health and environmental problems in support of the Agency's regulatory and compliance programs.**

Objective A. Research, design, and assess novel and advanced environmentally benign approaches for industrial processing and manufacturing.

Rationale

Sustainable development has been defined as development that meets the need of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Technology can have a profound effect on the environment both positively and negatively. The challenge is to use technology in such a way that it does not lead simply to short-term advances in productivity at the expense of long-term resource viability. A new generation of cleaner industrial manufacturing and processing technologies is needed to support pollution prevention, efficient resource use, and industrial ecology. Such a strategy can help the U.S. economy become more competitive by lowering resource and energy needs, reducing waste and emissions control costs, and fostering sustainable development.

Current Situation

According to the U.S. Council of Economic Advisers (1995), an investment in research and development has a private rate of return of 20 to 30 percent (i.e., benefit that accrues to the inventor) and a social rate of return approaching 50 percent (i.e., benefit that accrues to others).

Research and development is the source of new products that improve the quality of life and new processes that enable firms to reduce costs and become more efficient and competitive. Yet, most new chemical science and engineering technologies are focused on improving operations, increasing efficiency in the use of raw materials, and continuing to balance environmental and economic considerations. Few research and development resources are devoted to the design of alternative synthetic pathways for green chemistry, or the development of improved reactor, catalyst, or process designs in order to increase product yield, improve selectivity, or reduce un-wanted reaction byproducts. Scant resources are similarly devoted to innovative, quantitative methods for measurement and assessment for pollution prevention in process operations.

Research and Development Activities

1. Continued emphasis -- Chemistry for pollution prevention

The long-term goal of this research effort is to improve existing chemical design practices by developing more environmentally-benign chemical synthesis (i.e., green chemistry) and safer commercial substances. Green chemistry research was established to promote fundamental and innovative chemical methodologies that accomplish pollution prevention and have broad application in the industrial sector. It is the use of chemistry for source reduction, the highest tier of the risk management hierarchy as described in the Pollution Prevention Act of 1990 (West Publishing Co, 1992). Green Chemistry encompasses all aspects and types of chemical processes (e.g., synthesis, catalysis, analysis, monitoring, separations, and reaction conditions) that reduce negative impacts on human health and the environment relative to the current state of the art. Emphasis will be on: (1) an extramurally-focused program on green chemistry, and (2) in-house program on improved oxidation pathways.

Supporting fundamental research on chemistry. ORD will continue to support fundamental research to bring about new and innovative scientific breakthroughs in chemical and other industrial processes. The findings from this research will be targeted for use by industry in designing newer, more environmentally-benign products and processes. Areas of investigation include: development of innovative synthetic methods such as catalysis or biocatalysis; photochemistry or biomimetic synthesis; and the use of starting materials which are innocuous or renewable.

Developing and testing improved oxidation pathways. ORD will conduct research on improved oxidation processes that are less polluting and more energy efficient. Of all classes of industrial synthesis reactions, oxidation reactions are particularly polluting; typically, oxidation reactions are carried out at high temperatures and pressures, use chlorinated starting materials, and result in a large quantity of undesirable and toxic byproducts. Cleaner synthesis alternatives which include photocatalytic pathways and nonchlorinated starting materials will be investigated initially (e.g., UV/TiO_2 for clean organic systhesis). Development of novel reactor designs and other engineering

improvements which allow economic use of these alternative pathways will be integral to the research.

2. Continued emphasis -- Engineering for pollution prevention

Novel engineering approaches are being pursued to prevent and/or reduce pollution from industrial manufacturing activities -- both continuous and discrete processes. The scope of this research includes: equipment and technology modifications, reformulation or redesign of products, substitution of alternative materials, and in-process changes. Although these methods are often thought of in relation to the chemical, biochemical, and materials processing industries, they can also be utilized in many other industries such as semiconductor manufacturing, metals processing and other fabrication industries.

Supporting pre-competitive engineering research. ORD will continue to support pre-competitive engineering research in a variety of industries. Potential research areas include: improved reactor, catalyst, or process designs in order to increase product yields, increase selectivity, or reduce unwanted by-products. ORD will also support improved manufacturing processes that employ novel thermal or fluid and/or multi phase-specific systems resulting in significantly lower hazardous effluent production. New bulk materials and coatings with durability, long life, and other desirable engineering properties that can be manufactured with reduced environmental impact.

3. Continued emphasis -- Measurement, assessment, and feedback techniques for pollution prevention

Research and development in the physical sciences and engineering is being pursued which will lead to the development of novel measurement and assessment techniques for pollution prevention. Research in this area includes: LCA, computational simulations, and process design algorithms for product life cycle assessments, as well as the development of appropriate measurement methodologies to use as input for such assessments. The methods developed should provide the basis for scientifically sound and quantitative comparisons of the environmental impact of various technologies.

Supporting prevention-related evaluation research. ORD will continue to support research on quantitative methodologies for conducting life-cycle analysis which permit comparisons of environmental impacts of different pollutants on different media. Other areas of investigation include: algorithms incorporating pollution prevention into process design, intelligent control, simulation methodologies for process and manufacturing design, and improved intelligent sensors and control algorithms for real time, in-process multi-variate control of manufacturing equipment and systems to reduce waste material and hazardous emissions.

Developing intelligent controls for process operations. ORD will design approaches for predicting the performance of intelligent controls (IC) in pollution prevention applications. IC computational approaches based on fuzzy logic, neural networks, and generic algorithms are broadly applicable technology which can be used in many processes and sectors to reduce pollution from all media. IC-based approaches have the potential to make a major impact by preventing releases and increasing energy efficiency at affordable costs. As part of this effort, ORD will develop and demonstrate intelligent controllers in the laboratory and at pilot-scale facilities with various industrial, commercial, and consumer product partners (e.g., states, universities, environmental agencies, manufacturing and commercial industries, utilities, trade associations, federal organizations).

Objective B. Develop and test technologies and approaches targeted at specific environmental problems.

Rationale

As problems persist that pose high risks to both human health and the environment, the challenge is to develop economically attractive technologies and approaches that result in significant reductions in pollution over the longer term (e.g., the next ten to twenty years). while providing the maximum amount of human health and environmental protection. The federal government plays a critical role in advancing technologies and approaches to the point of joint, pilot and full-scale evaluation and demonstration. Government-supported research and development of cutting-edge preventive technologies and approaches helps industries of all sizes, but is particularly beneficial to medium- and small-sized industries which have neither the capability nor the resources to conduct their own programs.

Current Situation

While specific industries address many important knowledge gaps related to pollution prevention, the private sector does not generally sponsor research to address human health and environmental problems that cut across economic sectors, nor do they transfer proprietary technologies and approaches which give them an advantage over their competitors. Problems associated with persistent, bioaccumulative, and toxic chemicals (e.g., chlorinated compounds, metals) and volatile organic compounds (VOCs) exist in a number of industries and result from a variety of processes. Technologies and approaches that have the potential to yield marked improvements in preventing these pollutants can languish for years because the problem is owned by everyone and no one. Merely requiring industries to meet a regulatory limit or compliance standard does not guarantee their ability to do so. Medium- and small-sized industries in particular can suffer from a lack of capital with which to conduct research and development, and a lack of expertise with which to interpret and then employ technologies and approaches that are preventive in nature.

Research and Development Activities

1. Continued Emphasis -- Address problems associated with metals and organics via separations technologies for in-process recycling

Sustainable development places increased emphasis on "zero releases" from industrial processing. In-process recycling is an important part of the Agency's definition of pollution prevention and may be the best way to approach "zero releases" via direct recycling of a process stream back into the process from which it was generated. It enables recovery of valuable products, and can prevent or minimize releases of both toxic metals and organics. In-process recycling is best accomplished using separations technologies such as adsorption, membranes, filtration, distillation, or a combination of these. Emphasis will be on: (1) developing separations technologies for metals, and (2) developing and improving membranes for organic compounds.

Developing separations for metals. ORD will develop and demonstrate separations technologies based on adsorption and specialized membranes to reduce metals releases that are persistent, bioaccumulative, and toxic. The metals that will be targeted for investigation are chromium, arsenic, lead, copper, nickel, mercury and cadmium. Several specific projects will be pursued in developing in-process recycling for these metals. Among these are: developing high capacity, selective absorbents; making fixed-bed processes continuous; using electric fields for improved adsorption and regeneration; and improving energy efficiency and regenerability.

Developing membranes for organic compounds. ORD will develop and demonstrate membrane processes to show their capability for in-process recycling of organic compounds from manufacturing operations where they would otherwise be released as wastes. Initially, pervaporation processes will be investigated for in-process recycling of organics (e.g., acetic acid in pulp manufacturing, surfactant recovery in surfactant manufacturing). Other membrane and hybrid membrane/adsorption technologies will be investigated for organics recovery and recycling from air process streams (e.g., solvents from paint spray booths).

2. Continued Emphasis -- Address problems associated with global warming to reduce Total Equivalent Warming Impact (TEWI)

The application and demand for hydrofluorocarbons (HFCs) are increasing every year as these chemicals have become the simplest choice for replacing the ozone-depleting chlorofluorocarbons (CFCs) used in refrigeration and air conditioning applications. The decision to use HFCs has been driven by the need to stop ozone depletion, with less consideration given to their other potential environmental impacts. Although HFCs presently account for only 1% of the greenhouse gas (GHG) emissions, these are the fastest growing GHG emissions component and are expected to

reach 6% by the year 2010. Many of these chemicals have long atmospheric lifetimes (between 20 to 100 years) and have global warming potentials (GWP) several thousand times greater than CO_2.

Investigating TEWI alternatives. ORD will research and develop approaches to measure and minimize the TEWI performance of technologies using HFCs and HFC alternatives (e.g., ammonia, hydrocarbons, carbon dioxide), including technologies not dependent on vapor compression systems, and will evaluate those alternatives with the highest potential to reduce the TEWI contribution of a process. Examples of applications where reduced TEWI opportunities exist are motor vehicle air conditioners and supermarket systems, both of which are leaky systems. Alternatives under consideration include carbon dioxide for automobile air conditioners and a secondary loop system for supermarket refrigeration units where the primary refrigerant, such as ammonia, would be easily contained in an equipment room.

3. Continued Emphasis -- Address problems associated with VOCs and hazardous air pollutants (HAPs) by improving coating and cleaning operations

Surface coatings (e.g., paints, adhesives, inks, gel coats, lacquers, mold release agents) are an aspect of almost all manufactured items. Many of these surface coatings (and stripping or cleaning materials) were and still are manufactured with chemical solvents which improve ease of application. Because almost all of these chemical solvents are VOCs and HAPs, their release to air, water, and in wastes creates environmental problems that have become the focus of many domestic and international regulations and initiatives. The pressure of current and pending environmental regulations has spurred the development of many new, low VOC/HAP surface coating systems, including: UV curable coatings, powder coatings, waterborne coatings, low-VOC two-component coatings, high solids solvent-borne coatings, and 100% solids sprayable coatings. While these new coatings are making major inroads into markets that were at one time dominated by low-solids solvent-borne coatings, product development issues continue to limit the commercial availability and use of these systems in many applications. Emphasis will be on: (1) developing new coating and cleaning chemistries and equipment, and (2) adapting currently available coating cleaning chemistries and equipment to other applications.

Developing new and innovative coating and cleaning chemistries and equipment. ORD will conduct research to develop innovative, cost-effective, and low-pollution coating and cleaning materials and application technologies. Research will focus on technologies and chemistries that have the greatest potential for reducing risk through the minimization or prevention of VOCs and HAPs. A particular focus will be on hyperbranched polymers to produce superior coating formulations having little or no VOCs and HAPs. Hyperbranched polymers are an emerging class of polymeric materials. They display a low viscosity in spite of their high molecular weight. Replacing part of the linear polymer in a coating formulation with this low-viscosity polymeric material should

allow the amounts of organic solvents used in the formulation to be drastically reduced.

Adapting environmentally friendly coating and cleaning chemistries and equipment. ORD will test and evaluate the applicability of environmentally friendly coating and cleaning technologies to other industries, substrates, and applications. Efforts will focus on categories and substrates of interest to OAR, of greatest potential risk reduction, and/or with the greatest opportunity for use by medium- and small-sized industries. Of immediate interest will be the further development of an already demonstrated zero-VOC and zero-HAP coating system for wood substrates. This coating system, a two-part waterborne epoxy, can be tailored to expand its applicability to other substrates such as metal and plastics.

4. Increased Emphasis -- Address problems associated with products used indoors.

Consumer products and building materials (e.g., architectural coatings; dry cleaning spotting preparations; specialty cleaners and sanitation products; adhesives, caulks, and sealants; shoe polish and leather care products) can emit high levels of indoor contaminants known to pose a significant risk to human health. A study by EPA (Wallace, 1987) identified indoor air pollution as one of the most important environmental risks to the nation's health: (1) indoor levels 2 to 5 times higher than outdoors, (2) after some activities, indoor pollution levels can be up to 1000 times higher than outdoors, and (3) in new, nonresidential buildings, levels of VOCs can be as much as 100 times high than outdoors. Wallace also found that, on average, people spend 90% of their time indoors. Test methods and models can be used to better understand the emissions from these products and stimulate development and commercialization of lower-emitting products.

Developing test methodologies and models. ORD will identify products which emit high levels of indoor contaminants known to pose a significant risk to human health, develop appropriate test methods and models that can be used to better understand emissions from these products, and stimulate development and commercialization of lower-emitting products. This will include the evaluation of high-emitting sources to identify target compounds and potential preventive solutions and the evaluation of claimed low-emitting materials. Specific product categories that will be evaluated in the laboratory are architectural coatings and water-based cleaners. Interior paints will also be studied as part of a joint "Design for the Environment" project with OPPTS. Additional product categories will be added based on the literature reviews and on the needs of the program offices.

Supporting research on low-emitting materials and technologies. ORD will sponsor research on the development of low-emitting materials that are applicable across an industry. In some cases, an appropriate risk management strategy for reducing exposure to indoor air pollutants may be to develop a generic technology that will facilitate private

sector development of low-emitting materials. For some high-risk problems with the potential for a preventive approach, ORD will be able to bring together relevant parties and conduct cost-effective research that results in a generic technology to develop low-emitting materials. The specific industries will be selected based on the needs identified by in-house laboratory studies.

Objective C. Demonstrate and evaluate pollution prevention in support of Agency and Program Office priorities

Rationale

Supporting the Agency's regulatory and compliance programs with objective, scientifically sound pollution prevention technologies and approaches is an extremely important role that ORD plays. As part of this role, every effort must be made in cooperation with key stakeholders, to identify and evaluate technologies and approaches that result in significant decreases in pollution that is harmful to both human health and the environment. Both large and small industries can have significant compliance problems, but complying with environmental regulations can be particularly difficult for small, geographically dispersed industries or businesses. They do not have the capital, nor the technical capability to investigate, evaluate, or demonstrate pollution prevention technologies. Regardless of size and distribution, some industrial sectors have more difficulty than others in meeting EPA regulations. Pollution prevention technologies and approaches can be a particular problem unless both their economic and environmental effectiveness is clearly demonstrated. In many cases, collaborative research between industry and government is necessary to ensure that less-polluting technologies are accepted and applied.

Current Situation

Billions of pounds of chemicals are released annually which result in exposures that are both carcinogenic and mutagenic to human and animal life. Reductions in these releases to air, water, and in waste have resulted from concerted efforts by EPA and industry (e.g., 33/50, Design for the Environment). The chemical industry in particular has taken major steps to address the production of toxic chemicals and the impact of these chemicals and chemical byproducts on human health and the environment, but many industrial sectors still have difficulty in meeting Agency requirements. Efforts to address medium-specific problems using a multimedia approach (e.g., Source Reduction Review Project) have had mixed success. The Common Sense Initiative (CSI) is still a "work in progress" designed to realize the promise of pollution prevention as an important part of its mission across the six CSI-targeted industries.

Research and Development Activities

1. Continuing Emphasis -- Address problems associated with medium- and small-sized industries that pose high risk problems

ORD will continue to focus on medium- and small-sized industries with particular emphasis on those that are part of CSI. Because these industries are often poorly capitalized, run as small businesses, and geographically dispersed, they have difficulty in meeting regulatory and compliance requirements. They often do not have the expertise or the resources to devote to the research and development of advanced technologies and approaches that are less polluting, although they may be affiliated with a trade association that represents their collective interests. ORD has been successful in the past, and will continue to work in the future with those medium- and small-sized businesses and their trade associations which look to the Agency for assistance in reducing these risks. Emphasis will be on: (1) metal finishing, (2) printing, (3) computers and electronics, (4) auto refinishing, and (5) dry cleaning.

Working in the metal finishing sector. ORD will complete several pollution prevention projects identified by the stakeholders in this CSI industrial sector. Examples of these projects include the use of fume suppressants to control air emissions from hard chrome plating, near-zero-discharge evaluations, and Environmental Technology Verification evaluations for the metal finishing sector. This research will focus on investigating and demonstrating more cost-effective pollution prevention and control approaches. Once completed, the results of the projects will be disseminated to the user community as represented by the CSI workgroup.

Working in the printing sector. ORD will complete and implement several pollution prevention projects identified by the stakeholders in this CSI industrial sector. Examples of these include the use of waterborne inks and use of non-stick coatings on printing equipment. The goal of these will be to investigate and demonstrate more cost-effective pollution source reduction approaches and to disseminate these to the user community as represented by the CSI workgroup.

Working in the computer and electronics sector. ORD will evaluate pollution prevention and waste minimization technologies and approaches for this CSI industrial sector. Of particular emphasis will be wastewater and wastes contaminated with toxic metals (e.g., lead, arsenic) from the printed wiring board segment of the electronic interconnection industry. Many manufacturers can convert to processes which prevent or minimize pollution, but are concerned about maintaining product quality. Efforts will be targeted at demonstrating the effectiveness of these new technologies both in terms of economic and environmental effectiveness.

Working in the auto refinishing sector. ORD will demonstrate new and innovative technologies for the medium- and small-sized auto refinishing shops targeted at reducing the emission of VOCs. These technologies are being used by the auto manufacturers and large, automated auto refinishing shops. To enhance the penetration of the demonstrated technologies to the medium- and small-sized auto refinishing shops, a training program will be implemented once effective technologies have been demonstrated.

Working in the dry-cleaning sector. ORD will evaluate and demonstrate the efficacy of low-polluting technologies as alternatives to current methods of dry-cleaning using perchloroethylene (PERC). Candidate technologies for demonstration and evaluation include liquid CO_2, wet cleaning, ultrasound. Projects will consider the ability of these technologies to remove certain types of soils and stains (i.e., level of cleanliness), and their impact on selected types of fabrics (i.e., integrity and durability). The cost effectiveness of the technologies will also be developed and presented.

2. Continuing Emphasis -- Support Agency Rule Makings and Initiatives that Encourage Pollution Prevention

As a high-priority support activity identified by the Program Offices, ORD will continue to participate with the Office of Water, the Office of Solid Waste and Emergency Response, and the Office of Air and Radiation to investigate pollution prevention alternatives for those industrial categories involved in rule making or Agency Initiatives (e.g., Source Reduction Review Project, Common Sense Initiative). The projects will be nominated by the Program Offices and selected by ORD on the basis of their ability to achieve a meaningful and useful result with a broad applicability.

Supporting the Office of Water. ORD will support the Office of Water in the Source Reduction Review Project (SRRP) with an emphasis on pollution prevention. Ongoing and planned projects include pollution prevention evaluations in the oil and gas production area, pulp and paper manufacturing area, and transportation cleaning area. Other targeted research issues will be addressed as they arise. This research is a continuation of the efforts first identified in the Agency's Source Reduction Review Project. Now, with the Common Sense Initiative and based on general Agency policy, all regulatory efforts must consider pollution prevention opportunities while maintaining strict environmental standards. This research will be conducted in direct consultation with the various Common Sense Initiative Industry Subcommittees. Beyond the Common Sense Initiative industrial categories, the research will focus on needs within the pulp and paper industry and the industrial laundries industry. The identification of research needs will be collaborative with inputs from several sources, largely outside the government.

Supporting the Office of Air and Radiation. ORD will support the Office of Air and Radiation in the development of Maximum Achievable Control Technology (MACT) standards with an emphasis on paints, coating, and adhesives manufacturing, paint stripping, paper and other webs coating, printing and publishing, reinforced plastic composite production, metal furniture manufacturing, and other specific research areas as they arise. This research is a continuation of the efforts first identified in the Agency's

SRRP program. This research will be coordinated with industry trade associations, technology developers and users, and the Program Office.

Partnering with other Program Offices. ORD will work with the Office of Prevention, Pesticides, and Toxic Substances (OPPTS), Office of Solid Waste and Emergency Response (OSWER), and the Office of Environmental Compliance and Assurance (OECA) to advance pollution prevention through rule making and compliance assistance. This will be accomplished by targeting specific industrial sectors that are having difficulty in meeting compliance requirements, or that are dealing with persistent, bioaccumulative, and toxic chemicals (PBTs) released to the environment. The use of pollution prevention will be the primary means of achieving compliance or dealing with the PBTs.

Resource Allocation and Emphasis

Long-Term Goal II is an area of continuing emphasis under this research strategy. This area is one that has enjoyed support within the Agency and it is anticipated that such will continue into the foreseeable future. Research and development activities under Objective A will receive increasing emphasis as ORD enhances its in-house research and development program. Development of generic technologies and approaches which prevent pollution have the potential to be applied in a number of situations and ORD can play a unique role not likely be filled by other public or private entities. Most of the research and development activities under Objective B will continue to support high-priority EPA regulatory and regulatory re-invention efforts and will likely remain constant with some annual shifts in emphasis among industry sectors. ORD as a federal research organization has the responsibility and the capability for making a difference in this area, especially among medium- and small-sized industries faced with high-risk human health and environmental problems.

Long-Term Goal III: Verifying the Performance of Cleaner Products, Technologies, and Approaches

As part of its Environmental Technology Verification (ETV) Program, ORD will serve as a catalyzing organization to propel into the marketplace the most promising commercial-ready pollution prevention products and technologies from both the public and private sectors.

Objective A. Build a high-quality and efficient program to verify the performance characteristics of pollution prevention products and technologies

Rationale

Throughout its history, EPA has evaluated technologies to determine their effectiveness in

monitoring, preventing, controlling, and cleaning up pollution. Such data are needed by technology buyers and permitters both at home and abroad to make more informed decisions. Since the early 1990s, numerous government and private groups have identified the lack of an organized and ongoing program to produce independent, credible performance data as a major impediment to the development and use of innovative environmental technologies. With respect to products and technologies that prevent pollution, regulatory officials and private industry can make more informed decisions when scientifically sound data are available. Verifying the performance of products and technologies that prevent pollution can have an important impact both nationally and internationally in reducing pollutant loads in the coming decades. Pollution prevention innovations which have been systematically verified under the ETV Program will be more widely accepted by both the public and private sectors and the technical results of the verifications will quantify their preventive nature.

Current Situation

ORD has developed a program to verify environmental technologies across a wide variety of human health and environmental problems (EPA, 1997b). Among the most hopeful approaches to pollution prevention are the numerous products and technologies which not only protect the environment, but also save money. While many opportunities for such products and technologies have been identified over the last few years, few industry, manufacturing, commercial and even community organizations are willing to change their normal way of doing business and accept these new opportunities without documented, credible data. For this reason, pollution prevention products and technologies have significant difficulties in penetrating domestic and international markets, and the potential for significant prevention of pollution goes unrealized.

Research and Development Activities

1. **Continued Emphasis -- Verify commercial-ready products and technologies which substantially reduce or eliminate the production of air, water, and waste products**

   Hazardous Waste Pollution Prevention and Treatment ETV. In October 1995, ETV began one of its first pilot projects with the State of California to verify the performance of innovative technologies in hazardous waste pollution prevention, recycling, treatment and monitoring. In order to obtain the greatest number of technologies for verification, the initial solicitation was quite broad, but specifically stated that verification priority would be given to pollution prevention technologies. Although 45 proposals were received, few were in the pollution prevention arena. One of the first lessons learned for ETV is that focused solicitations, significant preliminary outreach to developers, or a single industry focus may be necessary to draw out technologies. This ETV pilot will continue operation with emphasis on outreach to the pollution prevention community and targeted industry groups being emphasized during 1997.

Industrial Coatings ETV Pilot. Based on the experience with the Hazardous Waste Pollution Prevention and Treatment Pilot, the ETV program began a pollution prevention pilot targeted at alternative products for one specific industry (i.e., industrial coatings) in October 1996. The coatings industry is a major source of VOC emissions to the environment and numerous innovative coating products are now under development. EPA's partner in this pilot is the Concurrent Technologies Corporation of Johnstown, Pennsylvania. A stakeholder's group of 25 participants met in March 1997, selected spray equipment for its first verification effort, and began the development of testing protocols. The pilot is on schedule to complete its first complement of verifications of metal parts coating by the end of the year and will move on to plastic substrates in 1998.

Metal Finishing ETV Pilot. Another ETV pilot targeted at a single industry (i.e., metal finishing) will be started in 1998. This industry is perceived to represent a substantial opportunity for pollution prevention technology alternatives and has the active backing of the Agency's Common Sense Initiative Committee. After selection of a partner organization and the formation of a broad stakeholder group, work will begin to select and verify new technologies that promise to assist this small-business sector.

Indoor Air ETV Pilot. In this ETV pilot, ORD and its partner, Research Triangle Institute, have instituted an extensive process to formulate a series of protocols to test products that impact the indoor air environment. The initial focus is on office furniture, office machines, and room air filtration systems. As stakeholder groups for each of these areas are formed, ORD will support validation testing using the protocols over the next few years. Stakeholders will follow protocol development and select additional product categories for verification in 1998.

Climate Change ETV Pilot. Pollution prevention techniques can be used as a cost-effective way to mitigate potential changes to the world's climate. By the end of 1997, ETV will put in place a new pilot to assess commercial-ready technologies that reduce the emission of greenhouse gases. Initial efforts are likely to focus on methane gas recovery systems, innovative cookstove technologies (used by millions in third-world countries), and other alternative technologies, such as fuel cells. A solicitation for one or more partner organizations and the formulation of an appropriate stakeholder group will occur later in 1997.

Air Pollution Prevention and Control ETV Pilot. By October 1997, ETV will have selected a partner organization for its Air Pollution Prevention and Control pilot. Like the Hazardous Waste Pollution Prevention and Treatment pilot, this effort will have both pollution prevention and pollution control technologies as a focus. EPA will begin this effort with an in-house evaluation of emulsified boiler and diesel fuels this summer and has issued an announcement seeking companies that would like to have their emulsified fuel verified. Emulsified fuels are designed to significantly reduce the release of NO_x into the

air.

Source Water Protection ETV Pilot. ETV will address the important area of prevention approaches to support sustainable community development in its recently funded Source Water Protection pilot. This pilot, which is expected to formally begin in 1998, will evaluate technologies that prevent contamination of ground and surface waters by typical infrastructure technologies such as pipelines and storage tanks. While partner selection is underway, EPA will work with Region I and the State of Massachusetts to evaluate innovative septic tank designs, addressing a problem that is a major source of pollution in New England and other parts of the country.

Resource Allocation and Emphasis

Long-Term Goal III is an area of significant emphasis and is particularly important since it is a Presidential Initiative. For the past several years it has been supported as a line item in the annual budget appropriation passed by Congress. The ETV program has been maintained at a level of approximately $10M since FY 1996, but the need for this level of funding is expected to decrease over the coming years. The intent is for the pilot programs to become financially self-sustaining and independent from EPA support by 2005. Technical staff currently dedicated to this effort will remain involved throughout the life of the pilot program. With a shift into the outreach and information dissemination phase of the program in the coming years, increased financial resources will be directed toward and staffed with expertise in technical information to develop and deliver research products through a variety of venues.

Long-Term Goal IV: Conducting Research which Addresses the Economic, Social, and Behavioral Aspects of Pollution Prevention

Through its extramural grants program, ORD will sponsor economic, social, and behavioral research to improve decision making and foster the adoption of pollution prevention by the public and private sectors at all levels.

Objective A. Develop and integrate social science and socioeconomic information and research products into environmental decision making

Rationale

With the Agency moving from a command-and-control approach of protecting the environment to one which is more collaborative and community based, old mind sets and ways of doing business must change. As a part of this change, EPA requires an improved understanding of why individuals and organizations make the decisions that they do regarding both human health and environmental protection. As other organizations embrace a preventive approach that goes

beyond improved housekeeping and easy fixes, the social, economic, and behavioral barriers to, and incentives for, pollution prevention must be understood and addressed. An improved understanding of the factors which are influential in moving individuals and organizations toward preventive risk management, will be of invaluable assistance in the evolving dialogue on environmental sustainability.

Current Situation

ORD initiated a research and development program in the area of economic, social, and behavioral research in 1995 as part of its newly created extramural grants program. This program of extramurally funded social science research and development will continue for the next several years. Such a program is particularly important to the Agency since many of its policies and programs must take into account both the benefits and the costs associated with Agency policies, rules, and regulations. Non-technical (i.e., economic, social, behavioral) data and information are increasingly a part of Agency decision making and this will continue to be the case well into the future. Unfortunately, there is a paucity of reliable, scientifically-based socioeconomic tools and methodologies available to assist Agency decision makers in collecting, analyzing, and then understanding such data and information. While EPA has made progress in developing and testing some tools and methodologies, much remains to be done. The Agency is facing numerous situations where incentives, other than regulatory or enforcement incentives, would assist in implementing preventive risk management.

Research and Development Activities

1. Develop Economic, Social, and Behavioral Tools to Improve Environmental Policies and Programs

There is a general lack of accepted tools for determining the benefits and costs associated with environmental problems and issues. The Federal government and EPA in particular are required to conduct cost/benefit analysis for all major regulations and legislative initiatives including those pertaining to pollution prevention. Government agencies responsible for policy analysis, statutory rules, regulatory decision making, and priority setting for environmental actions, including pollution prevention, will benefit from a set of systematic and credible tools for estimating the economic and social benefits and costs of a given action or set of actions. ORD can assist in providing this information through extramural research and development in such areas as environmental economics, public policy, alternative approaches to regulations, and the sociological (individual and organizational behavioral) dimensions of human health and environmental protection.

Understanding organizational decisions related to human health and environmental protection. ORD will continue to fund research through its extramural grants program to better understand those economic, social, and

behavioral factors that affect decisions on protecting human health and the environment. Both consumer and supplier relationships will be studied to better understand how behaviors are formed and how these behaviors influence decisions related to the environment. Organizational decision making approaches and their associated issues, particularly those which influence corporate actions in adopting pollution prevention over some other form of control or abatement are particularly of interest.

Understanding the economic benefits of pollution prevention policies and programs. ORD will continue to fund research through its extramural grants program to measure the economic value of health and environmental goods and services. EPA and other organizations must be able to determine if pollution prevention policies and programs are more cost-effective than traditional approaches. This research area will encourage proposals that improve methods for: (1) measuring environmental influences on human welfare, (2) assessing benefits of providing environmental information to industry and the public, and (3) valuing changes in environmental quality regulated by multiple pollution control laws or pollution prevention practices.

Understanding the economic costs of pollution prevention policies and programs. ORD will continue to fund research through its extramural grants program to strength the conceptual and empirical basis for cost estimation methods. Societal costs of environmental policies arise from changes in product quality, productivity, innovation and market structure. Industry increasingly abates pollution by changes in production processes instead of treatment, control and remediation. As a consequence, traditional financial and engineering methods must be augmented by dynamic models that incorporate substitutions, price changes, new technology, and innovation.

Developing relationships between economic growth and environmental quality. ORD will continue to fund research through its extramural grants program to develop relationships between environmental quality and economic growth. Current environmental policy promotes both, and some have argued that there is little or no conflict between these goals while others take the view that economic growth leads inevitably to increased environmental degradation. Research in this area will be encouraged to enlighten this debate and contribute to improved understanding of the relationships.

Resource Allocation and Emphasis

Long-Term Goal IV will continue to receive significant emphasis under this research strategy. Providing research and development products on the economic, social, and behavioral aspects of

pollution prevention is important if prevention is to be an effective risk management option in the future. This type of research will become even more important for the Agency as it moves to a community-based approach for environmental protection in the coming years. As the federal organization responsible for protecting this nation's environment, EPA must be well positioned to understand the economic, social, and behavioral issues that are an increasingly important aspect of its mission both in the near and longer terms. While all of this work will be conducted through the extramural grants program, ORD will consider developing an in-house capability for social science research. A decision on staffing and the nature of the in-house research is reserved until the results of the extramurally funded projects for the first several years are available.

4.0 MOVING FORWARD TO IMPLEMENTATION

This research strategy provides guidance and direction for ORD's Pollution Prevention Research and Development Program over the next five years. It is designed to be the first step in what will become a world-recognized, ORD-resident capability in providing the tools, methodologies, technologies, and approaches for advancing pollution prevention in the context of sustainable development well into the 21st Century. The next step is the translation of this strategy into an implementation plan. Those developing the implementation plan are encouraged to use the six priority-setting criteria that were presented in Chapter 2.0 and employed to focus the research strategy on the four Long-Term Goals developed in Chapter 3.0.

General Resource Trends

The enactment of the Government Performance and Results Act (GPRA) in 1994 and its implementation by EPA in FY 1999, places increased emphasis on goals and objectives which are measurable and achievable. With a greater emphasis on meeting the Goals, Objectives, and Subobjectives identified by the Agency in response to GPRA, increased stability in resource allocation and budgeting is anticipated. Pollution prevention is part of the Agency's Sound Science Goal and is described under that Goal's Pollution Prevention and New Technology (PPNT) Objective. All of the research and development activities described in this research strategy fall under one of several of the PPNT Subobjectives.

The actual allocation of resources for the various Objectives and Research and Development Activities described in this research strategy is not specifically defined at this time. However, it is reasonable to project trends based on the information that has been presented in Chapter 3.0. (Table 2.). Ultimately, the ability to sustain a research and development program in pollution prevention under GPRA will depend on the outputs and outcomes (e.g., products, accomplishments) described in the implementation plan and whether or not specific milestones have been met in a timely manner. As with all types of research and development programs, environmental research and development can offer no guarantees of success. Therefore, the resource trends identified in Table 2. are projections subject to a number of influences both internal and external.

Engagement and Partnership

While not a key scientific or technical issue, it is clear that engagement and partnering with a variety of stakeholders will enhance the adoption of pollution prevention. Pollution prevention frequently works best when efforts at preventing pollution are collaborative, involving many individuals and organizations that have a stake in seeing it succeed. The Agency is moving from

GOALS, OBJECTIVES, AND RESEARCH ACTIVITIES	ACTIVITY STATUS	RESOURCE TRENDS
Tools and Methodologies		
Tools and methodologies that are user-friendly		
1. Integrate risk assessment and risk management	New Activity	Increasing
2. Develop broadly applicable tools and methodologies	Increased Emphasis	Increasing
3. Develop targeted tools and methodologies	Continued Emphasis	Steady
Technologies and Approaches		
Advanced, environmentally benign approaches		
1. Advance Green chemistry for pollution prevention	Continued Emphasis	Steady
2. Advance Engineering for pollution prevention	Continued Emphasis	Steady
3. Improve Measurement, assessment, and feedback techniques	Continued Emphasis	Steady
Technologies and approaches that target problems		
1. Address problems associated with metals and organics	Continued Emphasis	Steady
2. Address problems associated with global warmers	Continued Emphasis	Steady
3. Address problems associated with VOCs and HAPs	Continued Emphasis	Steady
4. Address problems associated with products used indoors	Increased Emphasis	Increasing
Pollution prevention for Agency and Program Office priorities		
1. Address small industries that pose high risks	Continued Emphasis	Steady
2. Support Agency pollution prevention activities	Continued Emphasis	Steady
Performance Verification		
Performance verification of pollution prevention products and technologies		
1. Verify commercial-ready products, technologies, process changes	Continued Emphasis	Decreasing
Social Science		
Research to address the economic, social, and behavioral aspects of pollution prevention		
1. Develop economic, social, and behavioral tools	Continued Emphasis	Steady

Table 2. Pollution Prevention Resource Trends for the Next Five Years (FY 1998 - 2002).

a command-and-control approach in protecting both human health and the environment to one

that is based on environmental protection at the community level. As this happens, it becomes important for ORD to more fully engage a number of organizations in both the public and private sectors that are receptive to and supportive of pollution prevention research and development.

For pollution prevention to be adopted as the preferred approach for environmental protection, it is essential that ORD work more closely with individuals and organizations that are directly involved in the implementation of pollution prevention approaches, or that are influential in advancing the concept and routine consideration and use of pollution prevention, in both the United States and around the World. This includes EPA's Program Offices and the regulated sectors, and other stakeholders:

- States, communities, and tribes in order to better understand those situations at the community level where pollution prevention might best be employed. It will also raise the profile of pollution prevention as a routine part of the Agency's approach to community-based environmental decision making.

- Federal organizations in order to identify what research and development is needed to enhance the use of pollution prevention at federal facilities. It will also stress testing pollution prevention tools, methodologies, technologies, and approaches at government sites where they can be evaluated in real-world settings.

- The international community in order to exchange information on pollution prevention research and development and its implementation. It will also enhance perspectives on what other countries are doing to advance pollution prevention in the broader context of sustainable development, including the International Organization for Standardization's ISO 14000 standards for environmental management.

Delivery of Research and Development Results

ORD will strive to deliver its pollution prevention research and development results to the broadest possible audience. The goal is to enhance the access to, and use of, pollution prevention tools, methodologies, technologies, and approaches. To this end, ORD will use electronic technology (e.g., Internet home pages, distance learning) to the maximum extent possible. Electronic delivery offers a cost-effective, widely available means of delivering data, information, and results that can be easily accessed by both the public and private sectors. Pollution prevention research and development results developed by ORD will be designed to be available electronically, and ORD intends to be a major provider of pollution prevention research and development products via the Internet.

Implementation of this Research Strategy

This research strategy stresses the importance that pollution prevention can play in addressing high-priority human health and environmental risks. It does so within a framework that is both visionary in terms of pollution prevention's role in sustainable development, and being oriented toward meeting the more immediate needs of ORD's important stakeholders, the Program Offices and Regions. From this framework, comes the broad outline (i.e., the road map) for an implementation plan that now must be thoughtfully developed and diligently conducted in the coming years. This Pollution Prevention Research and Development Implementation Plan will be the final document that lays out the systematic research and development projects which will carry pollution prevention into the 21st Century and toward a vision of sustainable development both in the United States and throughout the World.

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APPENDIX I

EPA's Definition of Pollution Prevention (Habicht, 1992).

Under section 6602 (b) of the Pollution Prevention Act of 1990, Congress established a national policy that:

-- pollution should be prevented or reduced at the source whenever feasible;
-- pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible;
-- pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and
-- disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

Pollution prevention means "source reduction," as defined under the Pollution Prevention Act, and other practices that reduce or eliminate the creation of pollutants through:

-- increased efficiency in the use of raw materials, energy, water, or other resources, or
-- protection of natural resources by conservation.

The Pollution Prevention Act defines "source reduction" to mean any practice which:

-- reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling,treatment, or disposal; and
-- reduced the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.

The term includes: equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.

Under the Pollution Prevention Act, recycling, energy recover, treatment, and disposal are not included within the definition of pollution prevention. Some practices commonly described as "in-process recycling" may qualify as pollution prevention. Recycling that is conducted in an environmentally sound manner shares many of the advantages of prevention--it can reduce the need for treatment or disposal, and conserve energy and resources.

In the agricultural sector, pollution prevention approaches include:

-- reducing the use of water and chemical inputs;
-- adoption of less environmentally harmful pesticides or cultivation of crop strains with natural resistance to pests; and
-- protection of sensitive areas.

In the energy sector, pollution prevention can reduce environmental damages from extraction, processing, transport, and combustion of fuels. Pollution prevention approaches include:

--increasing efficiency in energy use;
--substituting environmentally benign fuel sources; and
--design changes that reduce the demand for energy.

APPENDIX II

Pertinent Data on TRI Chemicals Extracted from the Toxics Release Inventory (EPA, 1996b).

1. A total of 2.26 billion pounds of listed chemicals were released with approximately 1,556 million pounds released to the air (68.8%), 349 million pounds released underground (15.4%), 289 million pounds released to the land (e.g., landfills, surface impoundments) (12.8%), and 66 million pounds released to surface waters (e.g, rivers, lakes, streams) (2.9%).

2. A total of 3.8 billion pounds of listed chemicals were transferred to off-site locations with approximately 2,456 million pounds being sent for recycling (64.7%), 464 million pounds being sent for energy recovery (12.2%), 319 million pounds sent for treatment (8.4%), 298 million pounds sent for disposal (7.8%), and 255 million pounds sent to publicly-owned treatment works (6.7%).

3. The chemical industry (851 million pounds) and the primary metals industry (313 million pounds) were first and second in total releases in 1994, and their order reversed (primary metals - 1,142 million pounds and chemical industry (989 million pounds) for transfers.

4. Examples of chemicals released to the air -- methanol, toluene, ammonia, and xylene, released underground -- hydrochloric acid, ammonium nitrate (solution), ammonia, and methanol, released to surface waters -- phosphoric acid, ammonia, methanol, ammonium nitrate (solution), and released to the land -- zinc compounds, phosphoric acid, copper compounds, and manganese compounds.

5. The top ten carcinogens with the largest air/water/land releases were in descending order of quantity: dichloromethane, styrene, acetaldehyde, formaldehyde, chloroform, tetrachloroethylene, benzene, 1,3 butadiene, 1,2 dichloroethane, and chromium for a total release of approximately 177 million pounds.

6. A total of 26.5 billion pounds of TRI chemicals in wastes were managed by facilities in the following ways: treated on-site -- 8,659 million pounds (32.6%), recycled on-site -- 8,407 million pounds (31.7%), energy recovery on-site -- 3,423 million pounds (12.9%), 2,515 million pounds released or disposed of -- 2,515 million pounds (9.5%), recycled of-site -- 2,517 million pounds -- (9.5%), treated off-site -- 557 million pounds (2.1%) and energy recovery off-site -- 469 million pounds -- 1.8%).

7. Examples of chemicals involved in: recycling -- sulfuric acid (acid aerosols), copper, toluene, and lead compounds, treatment -- hydrochloric acid, sulfuric acid(acid aerosols) methanol, ammonia, energy recovery -- ethylene, propylene, methanol, mixtures and other trade names, and release/disposal -- methanol, hydrochloric acid, ammonia, toluene.

8. Thirty-two percent of all TRI facilities reported at least one source reduction (pollution prevention) activity in 1994 with reductions attributed to good operating practices, inventory control, spill and leak prevention, raw material modifications, process modifications, cleaning and degreasing, surface preparation/finishing, and product modifications.

9. Since 1988, EPA's baseline year for TRI comparisons, releases have declined by 44.1% with the chemical industry reducing releases by 622 million pounds, multiple codes by 304 million pounds and primary metals industry by 202 million pounds.

10. The total releases from federal facilities was approximately 9.8 million pounds with 83.7% released to air, 9.2% released to land, 4.5% injected underground, and 2.5% released to surface waters. The Department of Defense released 72.7% of the total releases followed by the Department of Energy at 9.9%, the U.S. Enrichment Corporation at 7.6%, the Department of Agriculture at 5.8% and Others at 4.0%.

11. A total of 10.4 million pounds of listed chemicals transferred to off-site locations with approximately 5.2 million pounds being sent for recycling (50.1%), 0.6 million pounds being sent for energy recovery (5.7%), 1.6 million pounds sent for treatment (15.7%), 2.7 million pounds sent for disposal (25.5%), and 0.3 million pounds sent to publicly-owned treatment works (3.0%). Of this amount, 94.5% of the transfers were by the Department of Defense of which 71.0% of that amount was by Army facilities.

12. A total of 30.0 million pounds of TRI chemicals in wastes were managed by federal facilities in the following ways: treated on-site -- 6.3 million pounds (21.0%), recycled on-site -- 4.1 million pounds (13.7%), energy recovery on-site -- 0.6 million pounds (2.1%), released or disposed of -- 11.5 million pounds (38.5%), recycled of-site -- 4.8 million pounds -- (16.0%), treated off-site -- 2,1 million pounds (6.9%) and energy recovery off-site -- 0.5 million pounds -- 21.0%).

13. Federal facilities projected a decline in TRI chemicals in wastes to 24.4 million pounds by 1996. Forty-eight percent of all federal facilities reported undertaking at least one source reduction activity in 1984.

APPENDIX III

Potential Adverse Human Health and Environmental Effects of the Top 25 TRI Chemicals with the Largest Air/Water/Land Releases, 1994 (EPA, 1996b).

CAS No. [1]	Chemical	Health Effects: Acute	Health Effects: Cancer [2]	Health Effects: Chronic	Health Effects: Developmental	Health Effects: Reproductive	Health Effects: Neurotoxicity	Health Effects: Other [3]	Environmental Effects: Ecotoxicity	Environmental Effects: Smog Formation	Environmental Effects: Ozone Depletion
67-56-1	Methanol				✓			✓			
7664-41-7	Ammonia		✓							✓	
108-88-3	Toluene						✓				✓[4]
1330-20-7	Xylene (mixed isomers)										✓[4]
75-15-0	Carbon disulfide				✓	✓	✓	✓			
---	Zinc compounds		✓		✓	✓				✓	
78-93-3	Methyl ethyl ketone										✓
7664-38-2	Phosphoric acid									✓	
7647-01-0	Hydrochloric acid		✓[5]		✓[6]						
75-09-2	Dichloromethane			✓	✓			✓			
7782-50-5	Chlorine		✓							✓	
--	Glycol ethers		✓		✓	✓	✓				
--	Copper compounds		✓		✓					✓	
--	Manganese compounds		✓		✓		✓			✓	
100-42-5	Styrene			✓			✓				
71-55-6	1,1,1- Trichloroethane										✓
74-85-1	Ethylene							✓			✓
79-01-6	Trichloroethylene			✓							
71-36-3	n-Butyl alcohol				✓						
108-10-1	Methyl isobutyl ketone				✓			✓			✓
7664-93-9	Sulfuric acid (acid aerosols)				✓					✓	
--	Chromium compounds		✓	✓[7]	✓	✓	✓			✓	
115-07-1	Propylene										✓
463-58-1	Carbonyl sulfide		✓					✓			
--	Lead compounds		✓	✓[8]	✓	✓	✓	✓		✓	

Table 1-1. **Potential Adverse Human Health and Environmental Effects of the Top 25 TRI Chemicals with the Largest Air/Water/Land Releases, 1994.[9]**

[1] Compound categories do not have CAS numbers (–).

[2] Distinctions among cancer classifications are discussed in the OSHA carcinogen section of this chapter.

[3] Toxicity resulting from the metabolite or degradation product of the parent compound.

[4] Contributes to ozone formation in the lower atmosphere; however, the extent of contribution to smog formation is unknown.

[5] Concentrated solutions are corrosive.

[6] Aerosol forms.

[7] Chromium VI is carcinogenic.

[8] Inorganic compounds.

[9] Sources: Integrated Risk Management System, Hazardous Substances Data Bank, PPT's Background Documents for Chemical Fact Sheets, EPCRA Section 313 Responses to Petitions, Agency for Toxic Substances and Disease Registry's *Toxicological Profiles*, and *Environmental Health Perspective*, Vol. 37, 1984.